Midterm experience with the Jarvik 2000 axial flow left ventricular assist device

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Objective: Rotary axial flow pumps have several potential advantages and disadvantages over pulsatile pumps. The Jarvik 2000 is distinctive in being intracardiac. We report our experience in 22 patients.

Methods: The Jarvik 2000 was implanted in 15 men and 7 women. Mean age was 38.8 (range 23–59) years, preoperative diagnosis was dilated cardiomyopathy in 16, postpartum cardiomyopathy in 3, ischemic heart disease in 2, and chronic allograft failure in 1. Twenty-one patients were in New York Heart Association class IV, and 1 patient was in class III. Nineteen patients were on inotropic support, 6 were supported with an intra-aortic balloon pump, and 2 patients had been salvaged with a Centrimag (Levitronix) ventricular assist device. The median pulmonary vascular resistance was 3 Wood units; median pulmonary capillary wedge pressure was 26.6 mm Hg; and mean Cardiac Index was 1.5 L/min/m².

Results: There were 2 early deaths and 6 late deaths. The average postoperative ventilation time and Intensive Treatment Unit stay was 2.2 and 10 days, respectively. One patient required a right ventricular assist device for short-term support and another for medium-term support. Seven patients were bridged to transplant, 3 had myocardial recovery, and 4 are ongoing. Mean and total duration of support was 280.5 and 6172 days, respectively. Driveline failures were noted in 3, but there were no pump infections or failure.

Conclusion: The Jarvik 2000 provides satisfactory intermediate-term results as a bridge to transplant or recovery. It appears to be associated with a low rate of serious driveline or pump infections and technical failure. However, bleeding complications due to the required anticoagulation treatment frequently occurred.

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The choice of left ventricular assist device (LVAD) remains controversial. In an attempt to address the limitations of pulsatile LVADs, axial flow pumps have been developed in recent years with a steady increase in their clinical use. The Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure (REMATCH) trial showed that pulsatile LVADs resulted in a 2-year survival of 23% in patients with end-stage heart disease compared with 8% for patients not receiving an LVAD but on optimal medical management. But these first-generation pulsatile pumps were associated with a significant number of

Abbreviations and Acronyms

CVA	= cerebrovascular accident
IHD	= ischemic heart disease
INR	= international normalized ratio
LVAD	= left ventricular assist device
REMATCH	= Randomized Evaluation of Mechanical Assistance for the Treatment of Congestive Heart Failure

adverse events.¹ The increasing use of ventricular assist devices in patients with end-stage heart failure provides an impetus to improve the performance of these devices for both short- and long-term use.

Axial flow pumps are generally smaller devices than the pulsatile pumps and may be associated with a lower incidence of complications.²⁻⁹ A recent early experience with the Incor (Berlin Heart, Berlin, Germany) LVAD in 24 patients has been reported with an acceptable level of complications.⁹ The Jarvik 2000 (Jarvik Heart, Inc., New York, NY) is a lower-flow device than the larger pulsatile pumps, providing an average flow of 3 to 4 L (max 6 to 7 L). The surgical trauma of implantation is lower than that with the larger devices. The pump is placed inside the left ventricle, avoiding the need for an inflow cannula, and the outflow graft can be connected either to the ascending or descending aorta. Furthermore, the smaller-diameter driveline is likely to be associated with a lower infection rate.

The aim of this study was to evaluate our clinical experience with the Jarvik 2000 axial flow pump implanted in a total of 22 patients between May 2003 and April 2006.

Materials and Methods

We retrospectively reviewed 22 patients implanted with the Jarvik 2000 LVAD between May 7, 2003 and May 7, 2006. Approval to implant the device was provided by the hospital clinical practice committee. Approval was also obtained by the Medicines and Healthcare Products Regulatory Agency. Informed consent was obtained from each patient.

Device Description

The pump consists of a small electromagnetically, implantable titanium (25 cm³, 90 g) intraventricular axial flow (single rotating vaned impeller) blood pump providing on average 3 to 4 L/min flow with a maximum flow of 6 to 7 L/min at 4 to 7 W of power against physiologic pressure.

The extraperitoneal power cable lead exits transcutaneously through the midpoint between the right upper and right lower abdominal quadrant and connects to the external controller.

Demographics

Fifteen patients were men and 7 were women. Mean age was 38.8 (range 23–59) years. The diagnosis was dilated cardiomyopathy in 16 (72.7%), postpartum cardiomyopathy in 3 (13.6%), Ischemic

heart disease (IHD) in 2 (9.1%), and chronic allograft failure in 1 (4.5%). Twenty-one (95.4%) patients were in New York Heart Association class IV and 1 (4.6%) was in class III. One patient was mechanically ventilated (4.5%), 20 (90.9%) patients were on inotropic support, 6 (27.2%) patients required a preoperative intra-aortic balloon pump, and 2 (9.1%) had support with a Centrimag (Levitronix, Zurich, Switzerland) centrifugal pump as a salvage and bridge-to-decision procedure.

Mean height was 173.7 ± 10.4 cm (157–185), mean weight was 70.0 ± 7.0 kg (60–74.8), and the mean body mass index was 23.2 ± 1.9 kg/m² (21.9–27.6).

Mean preoperative alanine transferase was 140.5 ± 216.2 IU/L (13–1344) and the mean bilirubin was 2.3 ± 1.4 mg/L (0.29–6.49). Creatinine was 1.41 ± 0.59 mg/L (0.45–2.94) and urea was 31 ± 20 mg/L (8.68–70.3). Mean serum albumin was 3.0 ± 0.6 g/dL (1.9–4.2).

Preoperative hemodynamic data revealed a mean pulmonary vascular resistance of 3.5 ± 2.7 Wood units (1.4–11.7), transpulmonary gradient of 7.6 ± 7.1 mm Hg (4–24), pulmonary capillary wedge pressure 26.6 ± 6.7 mm Hg (14–44), and cardiac index was 1.5 ± 0.3 L/min/m² (1.1–2.3).

Preoperative transthoracic echocardiography showed a mean left ventricular end-diastolic dimension and end-systolic dimension of 68.5 mm and 62.4 mm, respectively.

Surgical Approach

A median sternotomy with an ascending aortic anastomosis was performed in 19 patients and a left thoracotomy with a thoracic descending aortic anastomosis in the other 3 patients. The LVAD was implanted in 3 patients without the use of the cardiopulmonary bypass. In 6 patients, tricuspid valve annuloplasty was performed with the use of a standard Carpentier's ring size 32 for women and 34 for men. The cable power drivelines in all patients were introduced through the extraperitoneal abdominal wall, surfacing percutaneously through the midpoint between the right upper and right lower abdominal quadrant and connects to the external controller.

Postoperative Monitoring

All patients received peri- and postoperative hemodynamic monitoring and evaluation. A central venous line was used to assess the right heart filling pressures, and a Swan-Ganz catheter (Arrow International Inc., Reading, Pa) (in some patients) was used to assess cardiac output, pulmonary pressure, and systemic vascular resistance. However, a continuous transesophageal echo, by leaving the transesophageal echo probe in place during the first 48 hours after the operation, was the most valuable tool to assess filling of the right and left ventricles, right ventricular function, and septal deviation. The pump speed was generally kept low (speed setting 2; 9000 rpm) for all patients throughout the surgery, particularly when the chest was still open, to avoid any air suction to the left ventricle through the apex suture line, though biogluce was applied to minimize any further suction. However, in the later stages, the speed of the pump was adjusted, mainly by assessing the mean blood pressure, left ventricular filling and/or collapse, the septal deviation, and right ventricular filling and contractility. Most patients were given, at a later stage, adequate circulatory support at a speed setting of 3 (10,000 rpm) when intravascular

volume filling and right ventricular function were adequate. When patients were ambulated, some were increased to a pump speed of 4 (11,000 rpm). Intermittent pulsatility and aortic root ejections were maintained by applying the intermittent low-speed controller.¹⁰

Anticoagulant Treatment

Heparin treatment began the following day after surgery (target prothrombin time 2.0–2.5 times normal) and was subsequently converted to warfarin and 75 mg aspirin daily. The target range for international normalized ratio (INR) was 2.5 to 3.5. If the INR dropped to 2.0 to 2.5, half-dose low-molecular-weight heparin was administered, and if the INR dropped under 2, a full dose of low-molecular-weight heparin was given. Antiplatelet inhibition monitoring was performed in selected cases when bleeding complications occurred.

Statistical Analysis

Data are presented as mean or when indicated as median with standard deviation and range.

Results

The mean duration of support was 280.5 ± 232.3 days (range 6–683), and the total duration of support was 6172 patient-days. There were 2 early deaths as a result of sepsis and multiorgan failure following 8 and 23 days of support, respectively. There were 6 late deaths. One patient had a chest infection, which led to disseminated intravascular coagulation (DIC), and she died from a frontal lobe bleed after 44 days of support. A second patient developed bowel distension complicated by gastrointestinal bleeding, and he died after 84 days of support. A third patient had a bleed following the removal of epicardial pacing wires and developed acute tamponade, which required emergency exploration, complicated by multiorgan failure, and she died after 80 days of support. A fourth patient had a salvage pneumonectomy to secure intrapulmonary bleeding, and he died after 136 days of support. The fifth patient died from a hemorrhagic cerebrovascular accident (CVA) after 560 days of support. The sixth patient died due to device power cable failure, which occurred in the community after 291 days of support.

One patient (4.5%) required a right ventricular assist device (RVAD) for a short period of support (which was explanted 7 days later), and another continued having RVAD Levitronix support while the LVAD Levitronix was upgraded to a Jarvik LVAD. The mean duration of nitric oxide treatment was 1.4 days (range 1–3) days. The mean duration of ventilation was 52 ± 51.8 hours (range 12–168), and mean intensive care unit stay was 10 ± 13.6 days with a range of 2 to 48 days.

The median perioperative (during and 24 hours after the surgery) blood products transfused per patient were: 1.0 ± 1.2 U of platelets, 3.6 ± 4.1 U of fresh frozen plasma, and 5.8 ± 4.2 U of packed red blood cells.

Bridge to Transplant

Seven patients were bridged to orthotopic heart transplant after 92, 102, 116, 330, 409, 641, and 828 days of support. Six were successfully bridged, and the seventh died due to primary graft dysfunction.

Bridge to Recovery

Two patients with postpartum cardiomyopathy and one with dilated cardiomyopathy recovered after 253, 407, and 683 days of support, respectively. In all 3 cases, the device was left in situ by ligating the outflow line and most of the driveline was removed. All 3 patients are well and alive after a postimplant follow-up of 295, 446, and 567 days, respectively.

Home Discharge

Thirteen (59%) patients were discharged home while on support. Four patients are currently on ongoing support (3 of them at home) at 305, 319, 341, and 381 days of support.

Complications

Thromboembolism. Among the 3 patients who had descending aortic anastomosis, 1 developed an extensive clot in the ascending aorta and another had an embolic CVA after 560 days of support. Left ventricular thrombus was not noted in any of the patients.

Bleeding. Nine patients (41%) required reexploratory surgery for bleeding. Two patients (in addition to the patient with DIC described above) had frontal lobe bleeds, 1 patient had an occipital lobe bleed, 1 patient experienced gastrointestinal bleeding, and another patient was treated for a mediastinal bleed and tamponade that followed the removal of epicardial pacing wires.

Infections. Minor superficial driveline infections were noted and treated with antibiotics without the need for hospital readmission. One patient who developed mediastinitis and driveline infection was treated with intravenous antibiotics and drainage through a minimal surgical exploration. However, there were no pump housing or outflow line infections while on support.

Technical and pump failure. One patient experienced acute failure of the abdominal extension power cable after 293 days of support while in the community awaiting transplant. Another patient experienced partial failure of the implanted power lead close to the external connection. This resulted in several transient episodes of loss of function of the device. He was readmitted to the hospital, but no adverse clinical consequences occurred. The patient was subsequently successfully transplanted after 330 days of support. A third patient experienced driveline fracture and failure and had emergency surgical disconnection of the device (leaving it in situ) to prevent reverse flow after 683 days of support, as he had sufficient myocardial recovery.

He was successfully discharged home following this. No incidences of pump failure occurred.

Discussion

Our intermediate experience with the Jarvik 2000 has been encouraging, with relatively low rates of surgical trauma, pump infection, and pump failure and good device durability with a low rate of driveline infection. Our selection of this device was influenced by its distinct advantage of being an intraventricular, small-size, axial flow pump with no inflow cannula or chamber. Previous and concurrent clinical uses of this device in other centers have suggested satisfactory outcomes.¹¹⁻¹⁵

Selecting a particular device from the variety of devices available is often challenging.¹⁶ Among the factors that influence the selection and use of a particular device are: the size of the patient, concurrent right ventricular dysfunction, potential for hospital discharge, predicted duration of support and the likelihood of recovery or destination therapy, the required anticoagulant treatment, the experience of the implanting center in a specific type of device, and the cost of the procedure and device.

The REMATCH trial rendered the pulsatile pumps (specifically the HeartMate I [Thoratec, Pleasanton, Calif]) as the gold standard and benchmark for mechanical assist support for end-stage heart failure.¹ However, the success of these pumps was limited by a significant rate of device-related complications. In particular, infection, bleeding, and mechanical failure of the device were major factors in the 2-year survival rate of only 23%. In an attempt to reduce these frequent and serious complications and to simplify the device insertion and minimize the associated surgical trauma, improve function, and durability and expand the potential pool of patients that can be candidates for support, axial flow pumps have evolved and have been introduced into clinical practice. The Incor, HeartMate II, MicroMed DeBakey (MicroMed Cardiovascular Inc, Houston, Tex), and the Jarvik 2000 devices are the most frequent axial flow devices in recent clinical use.

In our experience, the surgical insertion was not complex and was simpler than that for the HeartMate (XVE) device. We performed left thoracotomy and connected the outflow graft to the descending aorta in the first 3 patients receiving a Jarvik device. This method of implanting the Jarvik (connecting the outflow graft to the thoracic descending aorta via left thoracotomy) is reported by Frazier and colleagues¹⁴ with satisfactory results. However, there were 2 main reasons that made us change to median sternotomy, which involves connecting the outflow graft to the ascending aorta. First, in our early experience, 2 out of 3 patients experienced thromboembolic complications (1 patient had ascending aortic clot and the other had an embolic CVA), and

second, it gave us the flexibility to insert an RVAD if necessary through the median sternotomy.

The LVAD Jarvik was inserted in 3 patients without the use of cardiopulmonary bypass. All patients survived and RVAD support was not needed in these cases. Off-pump LVAD insertion could be safely used when the patient was able to tolerate lifting of the heart to allow exposure and easy access to the apex.

We experienced a high rate of acute postoperative bleeding despite minor surgical trauma, which could be explained partly by the high incidence of preoperative liver dysfunction among our group of patients. Late bleeding was all related to the required anticoagulation treatment. A 42% frequency of postoperative bleeding occurred in the REMATCH trial, and reoperation for bleeding was reported by Goldstein¹⁷ as the most common complication following implantation of the MicroMed DeBakey LVAD.¹

Driveline and device pocket infections are frequent, serious, and challenging complications for assist devices in general and pulsatile pumps in particular. We, like others, found a low rate of driveline and device-related infection.^{18,19} The small size of the device and the lack of abdominal pocket, inflow cannula, or valves combined with an insertion that is associated with relatively minor surgical trauma with a flexible and stable driveline are among the factors that contribute to a low rate of serious infection with this device.

Among the pulsatile pumps, the REMATCH investigators reported that sepsis in particular was one of the major factors in the 2-year survival rate of only 23%.¹ On the other hand, the experience with a large series of the MicroMed DeBakey axial flow pumps showed a particularly low rate of device-related infections and sepsis.¹⁷ In an earlier laboratory and clinical experience with the Jarvik 2000 device, it was reported that rigid fixation and the vascularity of scalp skin promoted healing and reduced the risk of driveline infection.¹⁸⁻²⁰ However, as we mentioned previously, our preferred percutaneous driveline exit site was the abdominal wall mainly due to the simplicity of the procedure.

With the Jarvik 2000, we experienced no pump failure, although there were 3 (13.6%) driveline failures. The reported experience with the MicroMed DeBakey and Incor showed a low rate of device mechanical failure.^{9,17} The causes of mechanical failure in the MicroMed DeBakey pump included a recessed connector pin ($n = 2$), a broken wire ($n = 1$), and a controller failure ($n = 1$).¹⁷ A controller intermittent malfunction was the only reported mechanical failure in the Incor pump.⁹ Mechanical failure continues to be a major problem with the pulsatile devices despite improvements in design.²¹ The probability of device failure in such devices was 35% in the REMATCH study at 24 months, and the device was replaced in 10 patients.¹ The lack of pump failure in our series is attributed mainly to the

basic design of the device, with the single movable component being an impeller located in the center of the titanium housing.

Our primary goal for using the Jarvik 2000 was in principle as a bridge to transplant. So far, we have bridged 7 patients (31.8%), 6 of them (85.7%) successfully. The shortage of organs available for transplantation limited bridging higher numbers of patients. However, the small size of the device and low rate of driveline and pump infection are features of this device that also support its use as destination therapy.²²⁻²⁴

One of the main concerns regarding the Jarvik 2000 miniaturized axial flow pump is whether it can provide sufficient flow and support for day-to-day physical activity as it provides lower flows than other devices. We feel that the initial acute postoperative recovery rate (mainly intensive care unit stay) is initially slightly faster due to lower surgical trauma, blood transfusion, and so on, but the next recovery phase is slower in these devices, which could be related to it being a low-flow device. Later on, this device provided satisfactory flows and support for patients to maintain a reasonable quality of life and maintain good physical activity at hospital and home. At present, 4 patients are on ongoing support, and 3 are at home. The long battery life, light power source, and simple, small, user-friendly device controller with no reported pump failure have made it relatively easy to discharge patients home as soon as they recover. However, a longer period will be needed to evaluate the reliability and outcome of the device.

Conclusions

The Jarvik 2000 LVAD gives satisfactory midterm results similar to other axial flow pumps. It has some advantages over the pulsatile pumps in terms of lower surgical trauma, pump infection, and pump failure and durability. However, more clinical experience, longer follow-up, and further evaluation are needed.

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